A MULTIMEAGAVOLT GENERATOR FOR HEMP SIMULATION*

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Abstract

A multimegavolt HPD pulse generator was developed and tested for the U.S. Navy for use in HEMP testing of aircraft. The pulser produces a repeatable, fast-rising, double-exponential HEMP pulse. The pulser utilizes state-of-the-art distributed peaking capacitors and a single greater than 2 MV output switch. Detailed electrical and mechanical analysis was done to assure the integrity and reliability of the pulser.

The pulser is located 30 m above the ground within an HPD antenna and therefore requires electrically isolated remote control and diagnostics for monitoring its performance. The capability to rapidly find and correct problems is critical for EMP simulator operation because of the high cost of test operations, and limited availability of test objects.

Introduction

Maxwell Laboratories, Inc. (MLI) has designed and built a multimegavolt HPD EMP generator system for the Naval Surface Weapons Center for use in testing naval aircraft. Maxwell has built other pulsers of this type including TORUS and a 2 MV pulser built for the French Army as described elsewhere (1) (2).

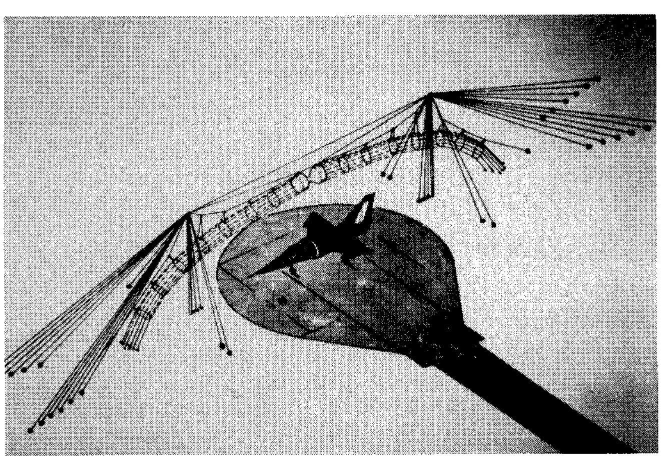

Figure 1. HPD Simulator.

The pulser utilizes a carefully designed bicone structure that integrates the output switch, peaking capacitors and bicone extension structure into an almost constant impedance bicone. This design minimizes diffraction effects which degrade high frequency performance. Figure 1 shows a HPD pulser located in its antenna in the firing position.

The pulser system incorporates a complete diagnostic and trigger package which facilitates operation and maintenance. This package is powered by a hydraulic generator system that provides the electrical isolation necessary for a HPD pulser without the use of batteries. The Marx generator is designed for easy maintenance. Each tray can be separately removed. All tray components can be inspected without removing the tray.

HPD Simulators

HPD simulators are used to simulate HEMP (High Altitude Electromagnetic Pulse). HEMP testing is done primarily with horizontally polarized EMP along the axis of the aircraft where it has the largest coupling. The pulser is located at the apex of an elliptical antenna. The elliptical section of the antenna is of circular cross section and is resistively loaded. A pair of cones in the antenna taper the wire down to the pulser. The pulser itself forms a part of the antenna and carries the conical structure down to the apex of the cone.

When the pulse fires it launches a spherical wave onto the bicone antenna which has an impedance given in equation (1).

$$Z_{bc} = \frac{Z_o}{\pi} \ln[\cot(\theta/2)] = 60 \ln[\cot(\frac{\theta}{2})]$$

where

θ = Bicone angle

Z_{bc} = Bicone impedance

$$E = \frac{60\, V_o}{Z_{bc} r \sin(\theta)} \qquad (2)$$

where

V_o = the pulser voltage

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14. ABSTRACT
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r = distance from the apex of the pulser

θ = Angle from the pulser axis

When the edge of the wave reaches the transition from conical antenna to cylindrical antenna there is a change in impedance. This causes diffraction to occur which makes equation (2) above inaccurate after the diffracted wave arrives. The time between the initial wave arriving and the diffracted wave arriving is known as the bicone clear time of the antenna. This varies with the position of the observer. In the case of the NATC antenna, this time varies from 25 ns for an observer inside the pulser to about 7 ns in the far field. In the working volume the bicone clear time is about 8 ns. The diffracted wave "clips" off the top of the waveform. This causes the real amplitude to be slightly lower than predicted by (2) and it also makes the field risetime faster. The late time portion of the pulse is produced by the elliptical antenna. The resistors in the antenna are used to terminate the wave and minimize oscillations.

Peaking Circuits

The relatively high series inductance of the Marx generator prevents it's being used to directly produce the required fast rise pulse. Therefore, a peaking circuit is used. (3) (4). A typical Marx generator-peaking capacitor EMP pulser circuit is shown in Figure 2.

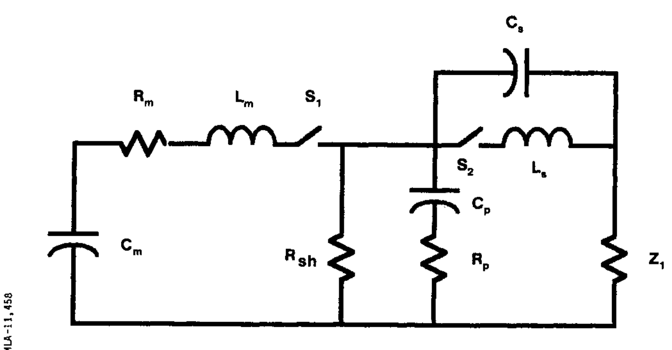


Figure 2. Typical Peaking Circuit Used in EMP Pulse Generator.

where:

C_m	=	Marx equivalent capacitance
R_m	=	Marx equivalent series resistance
L_m	=	Marx equivalent series inductance
R_{sh}	=	Marx shunt resistance
C_p	=	Peaking capacitor
R_p	=	Peaking capacitor equivalent series resistance
C_s	=	Output switch stray capacitance
L_s	=	Series inductance of the peaking switch circuit
Z_1	=	Impedance of the load

By proper selection of the peaking capacitor it is possible to produce a double exponential pulse from this circuit. Switch S_1 closes at t=0, which represents Marx erection. The Marx then charges the peaking capacitor C_p. This circuit forms a LC network and the voltage on the peaking capacitor rises as a Vo(1-cos(wt)) waveform. If the peaking capacitor is selected such that the peak current in the tank current matches the required load current at switch out, a double exponential pulse will be produced if S2 is closed at the current peak. The derivation of this is discussed in detail in reference (2).

Peaking Circuits in HPD Generators

To produce nanoseconds risetime with amplitudes of greater than 2 megavolts it is necessary to pay very close attention to the peaking circuit and output switch geometry. This circuit must be close to a bicone geometry to maintain constant impedance from the apex of the bicone to the antenna attachment point. Figure 3 shows a section view of the pulser. Marx generators are located at each end of the pulser that produce plus and minus greater than 2 megavolts in normal operation. Trigger systems located at each end of the pulser trigger each Marx, which results in Marx

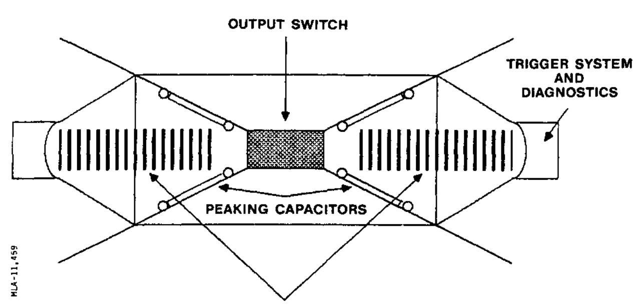
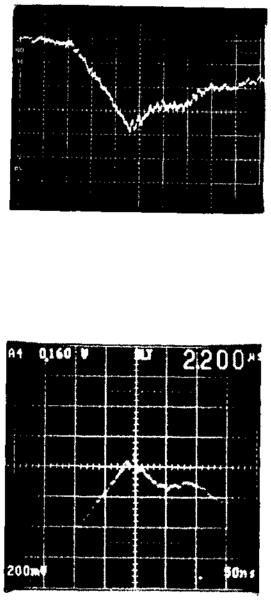


Figure 3. Section View of Pulser.

erection. The Marx generators pulse charge the peaking capacitors to greater than 2 megavolts in about 150 ns. This produces multimegavolts across the output switch. The output switch then closes, which launches a spherical electromagnetic wave from the apex of the bicones. This wave propagates with minimum perturbations because of careful attention to detail in the peaking circuit. Figure 4 shows the actual measured voltage.



FAR PEAKER VOLTAGE

NEAR PEAKER VOLTAGE

MLA-11,460 SWEEP RATE 50 ns/div

Figure 4. Actual Peaking Capacitor Waveforms.

Test Results

The pulser was tested at the Maxwell facility in San Diego, CA. prior to shipment. Testing was done over a range of 650 kV to greater than 2 MV. A summary of the pulser specifications and measured performance are summarized in Table 1.

TABLE 1

Specification	Required	Measured
Peak Output Voltage	>2 MV	>2 MV
Peak Output Switch Current	>25 kA	34 kA
Risetime:	<10 ns (10-90%)	8 ns (10-90%)
Pulse Duration	>300 ns e-fold	>330 ns
Prepulse Current	<4% of peak	6% of peak
Reproducibility	<10% of peak	
Prefire	<5%	None recorded in 100 shots at 5 MV
System Jitter (One Sigma)	<25 ns	4.5 ns

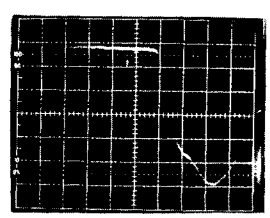
The pulser was placed on a wooden stand as shown in Figure 5. This stand placed the apex of the pulser 4.7 m above the ground. This was done to prevent flashover to the ground and to prevent ground reflections from disturbing field measurements. Aluminum slats in a conical array were used to electrically extend the bicones so that the MGL-6 free field probe would measure the peak field before waves scattered from the ends of the cone arrived at the probe. These cones provide 16 ns bicone clear time from the probe location 5.05 m from the bicone apex. The probe was located on a plastic and wooden stand at the same level as the pulser apex, 4.7 m above the ground.

MLA-11,328

Figure 5. Pulser on Wooden Test Stand.

After initial system checkout a 120 shot final test was completed consisting of 110 shots at greater than 2 MV, and 10 shots at 650 kV. In each of these shots peaker voltage on each end of the pulser and the radiated magnetic field at 5m was recorded.

Figure 6 shows a typical shot from the greater than 2 MV series. The 10 to 90% rise time is 8 ns. Notice that the pulse rises to about 70% of its peak amplitude in 4 ns. This high B-dot signal produces the large high frequency content which is critical to EMP testing. The pulse reaches peak in 12 ns, and at 15 ns the diffracted wave from the bicone extension arrives and clips the tail of the waveform. When the pulser is in the antenna the bicone clear time will be reduced to 8 or 9 ns which will reduce the peak amplitude and also enhance the risetime. System jitter was 4.5 ns from a low level (10 Volts) trigger input.



5 ns/div

63 kV/m/div

MLA-11,463

RISE TIME (10-90%) 8 ns

Figure 6. Radiated Waveform Using MGL-6 at 5m From Pulser.

Command & Control System

The elements in the trigger system for each marx generator are illustrated in Figure 7. The master trigger signal is delayed and transmitted over a wideband fiber optic trigger link to the command and control enclosures located on each end of the pulser. The link produces a 70 V fast rising pulse to trigger a Maxwell 100 kV output trigger generator. This trigger generator has two 50 ohm output cables that are used to trigger the Marx generators in m = 2 configuration.

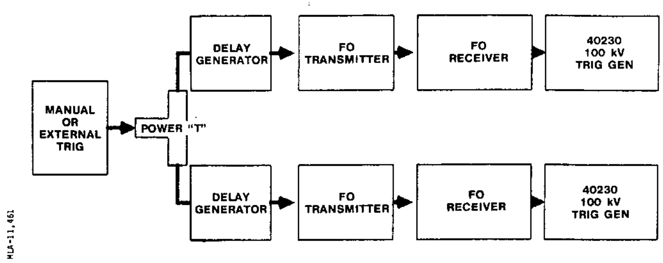


Figure 7. Elements of Trigger Systems.

Figure 8 shows a block diagram of the C&C system. The C&C system can provides trigger, diagnostics, and safety system and is located in enclosures on each end of the pulser.

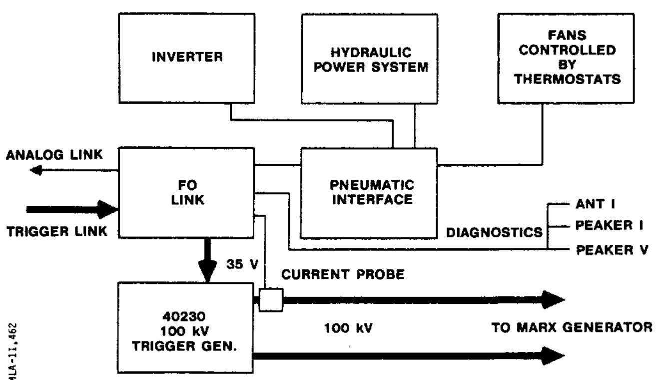


Figure 8. Block Diagram of C&C System.

A hydraulic power system is located in the lower bay of the C&C enclosure. This power system regulated by a servo valve that regulates the flow of hydraulic fluid and therefore the speed of the hydraulic motor and generator. This power is than further regulated by a fre-quency converter. The enclosure has internal lighting powered by the hydraulic system or "shore power," which facilitates maintenance at anytime of the day or night.

The regulated power is controlled by the power distribution unit that is used to remotely control the pulser. This unit converts pneumatic signals to electrical signals which intern control the state of the pulser.

The control console offers complete monitoring of the pulser system. Each subassembly can be turned on remotely, and their state monitored. The fiberoptic system utilizes coaxial relays so that various points in the trigger system maybe monitored without lowering the pulser.

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